Silicon nanoelectronics and nanotech innovation

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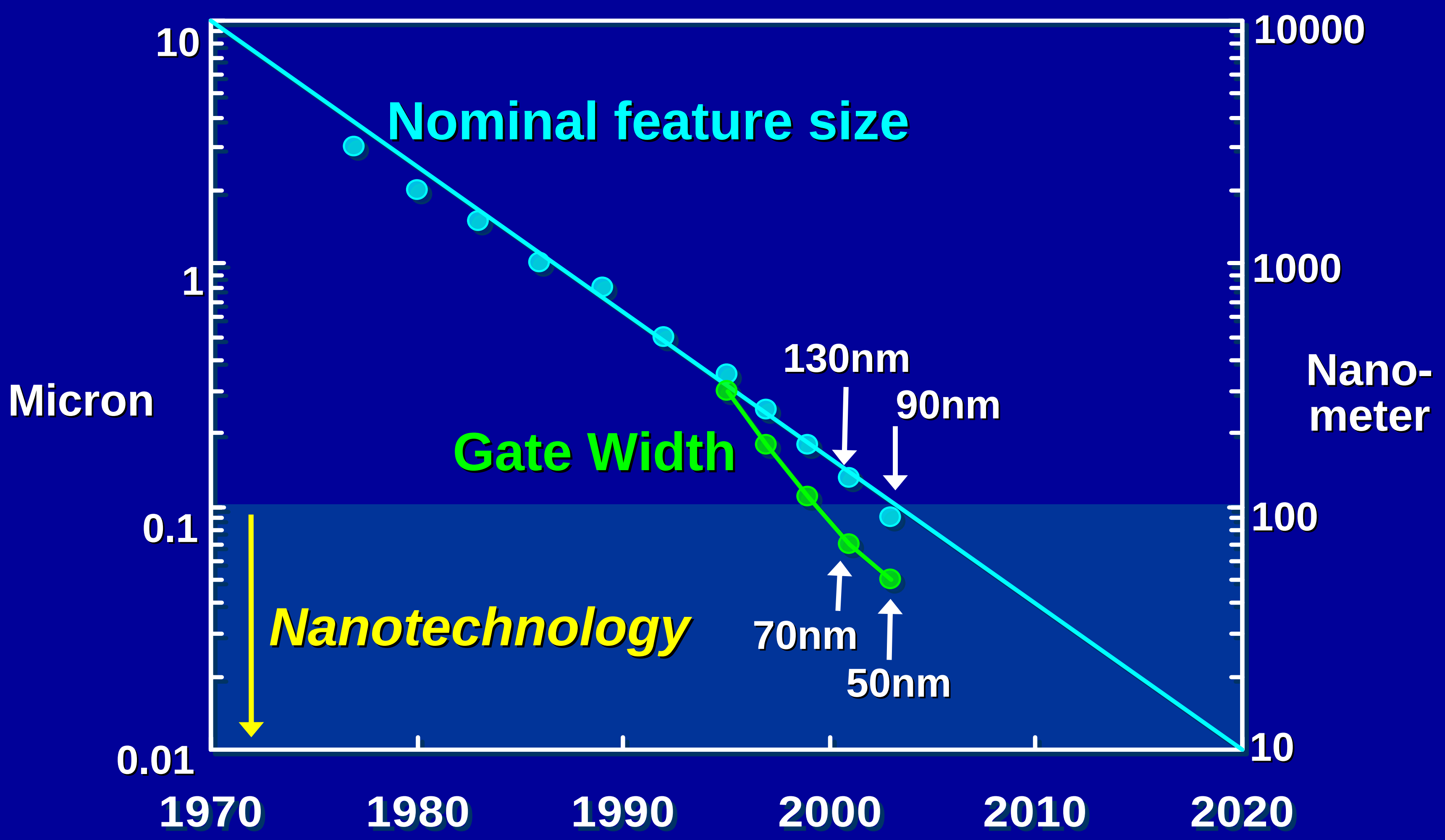
Intel Corp

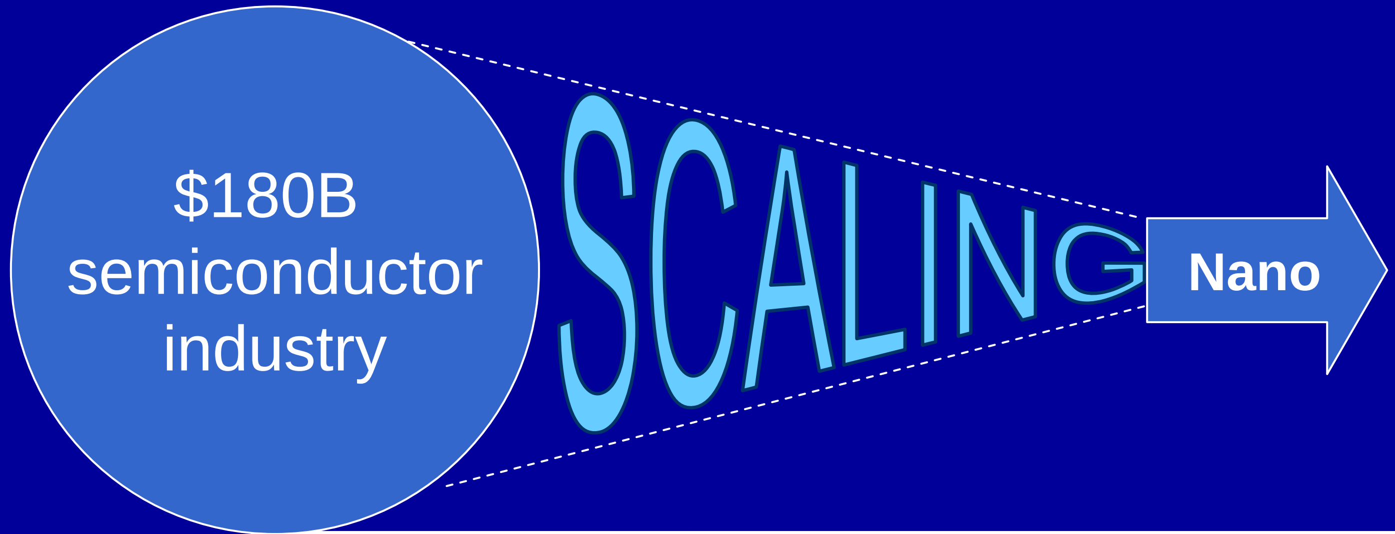
Key messages

- Extending Moore's Law
  - enabled by nanotech innovation
- Expanding Moore's Law
  - The silicon manufacturing infrastructure can enable novel nanotechnology
- Integration of nanotechnology
  - Silicon provides the platform
- Radical new nanotechnologies beyond CMOS will emerge by 2020

Silicon Nanotechnology is Here!



Extension of Moore's Law



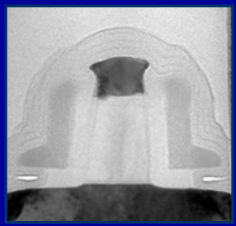
1. Scaling device dimensions downward
2. Scaling wafer diameter upward

	1990	1995	2000
DRAMs	4 MB	64 MB	1 GB
Feature size	0.8 µm	0.35 µm	0.15 µm
Wafer diameter	6"	8"	12"
Cost per Megabit	$6.50	$3.14	$0.10

Powerful economic engine will drive innovation

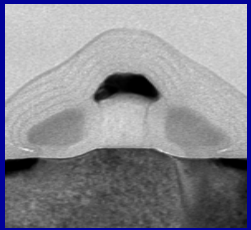
Nanotechnology will extend CMOS scaling

90nm Node
2003



50nm Length
(IEDM2002)

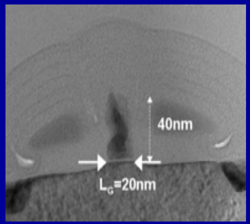
65nm Node
2005



30nm Prototype
(IEDM2000)

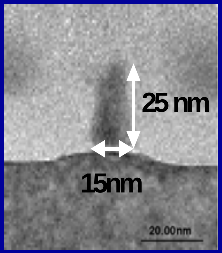
----2003

45nm Node
2007



20nm Prototype
(VLSI2001)

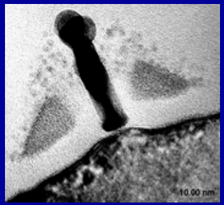
32nm Node
2009



15nm Prototype
(IEDM2001)

–2012 —

22nm Node
2011



10nm Prototype
(DRC 2003)

Nanotubes,
nanowires

1-3nm

16 nm node
2013

7nm

----2013 –2017

11nm node
2015

5nm

8 nm node
2017

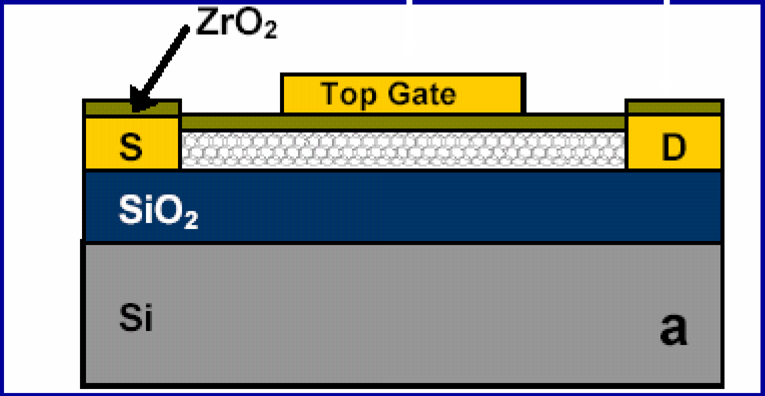
3nm

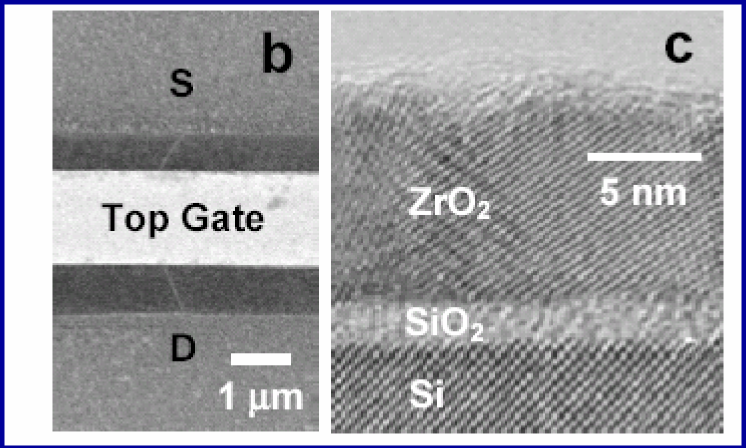
Innovations like quantum dots,
Nanowires, Naotubes, etc.

Extending CMOS-Nanotubes

E-beam Ti/Au gate

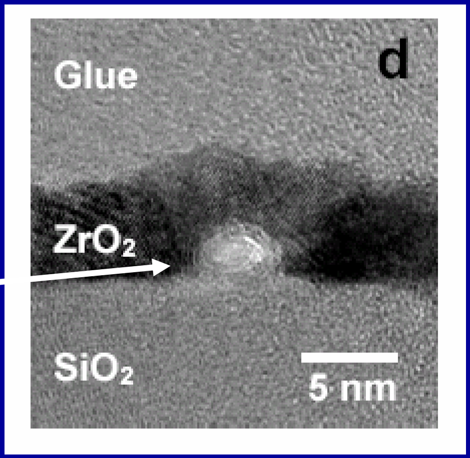
Mo S/D





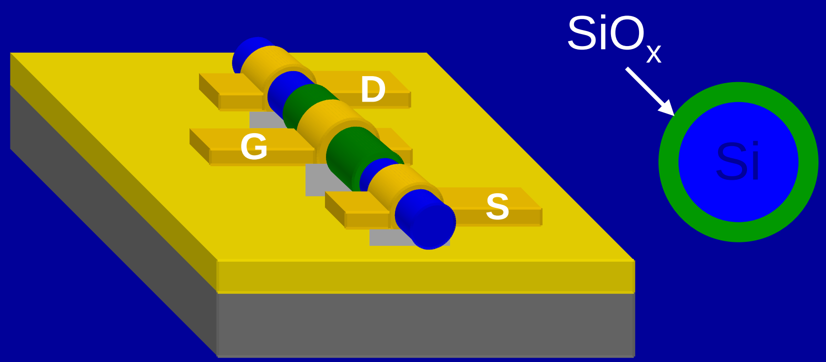
8 nm ZrO2

1.4 nm diameter single wall CNT

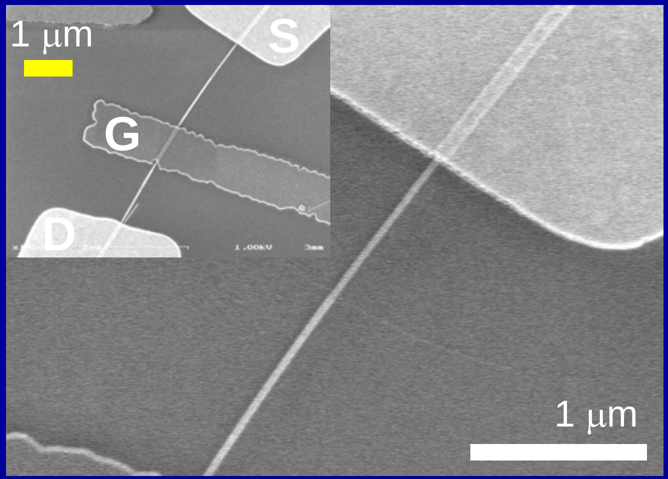


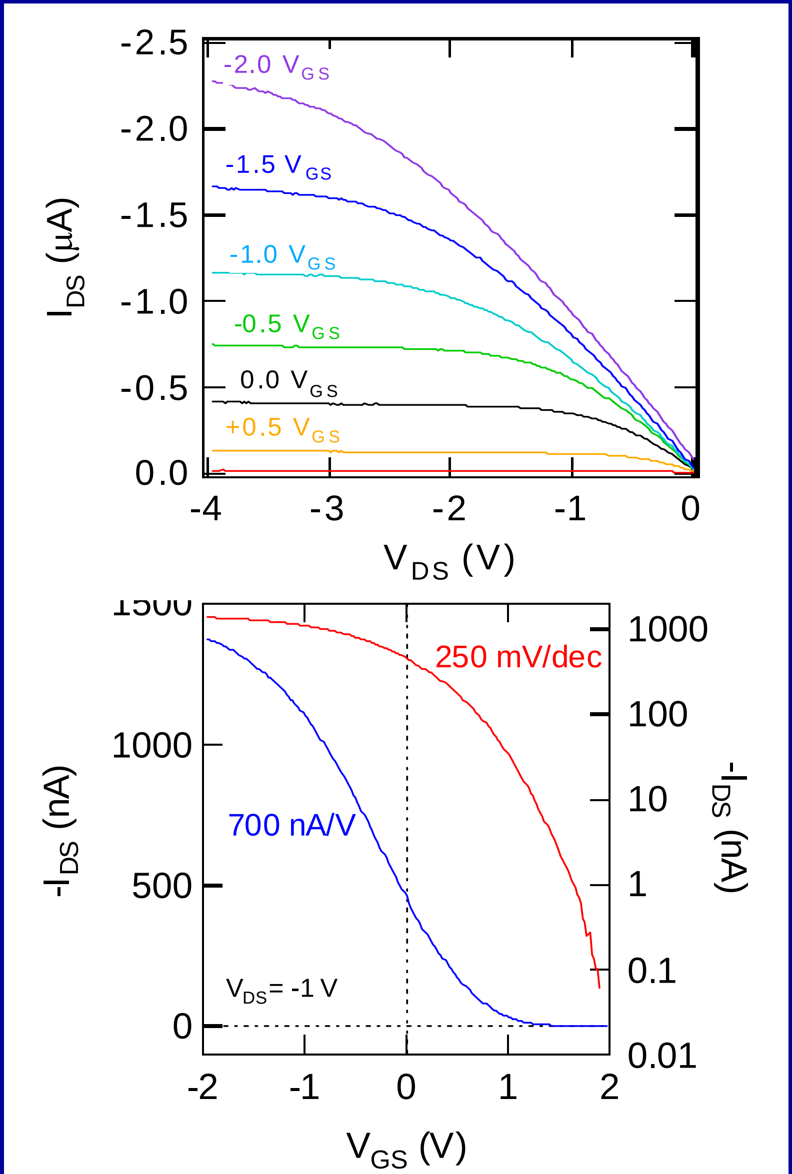
McEuen et. al, . Cornell Universwity

Extending CMOS - Nanowires

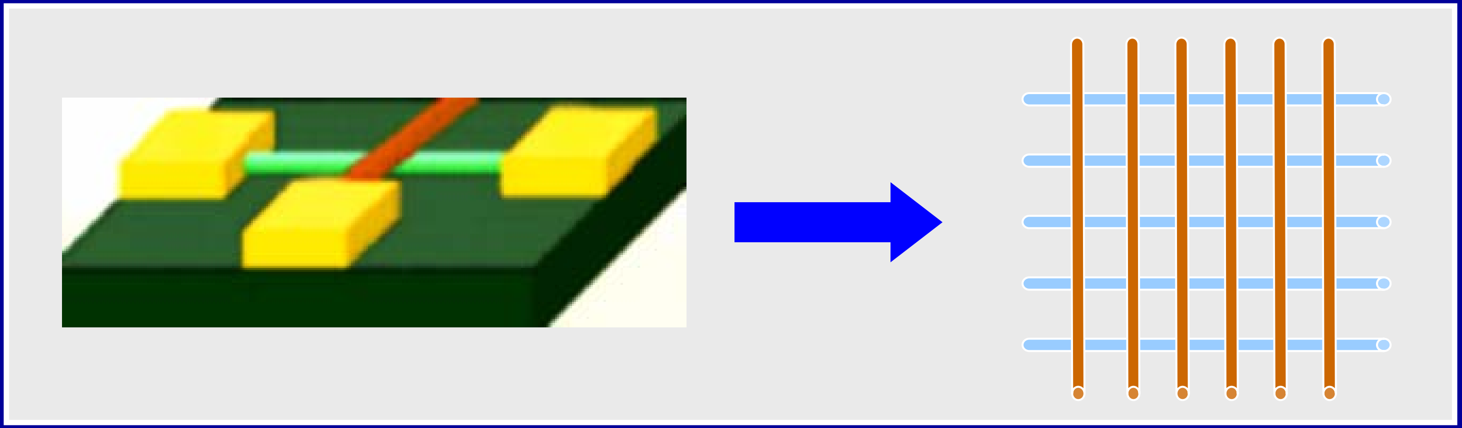


C. Leiber et. al. , Harvard U





Extending CMOS
Crossed Nanowire Structures:



- Nanowires serve dual purpose: both active devices and interconnects.
- All key nanoscale metrics are defined during synthesis and subsequent assembly.
- Crossed nanowire architecture provides natural scaling and potential for integration at highest densities.
- No additional complexity (with added material).

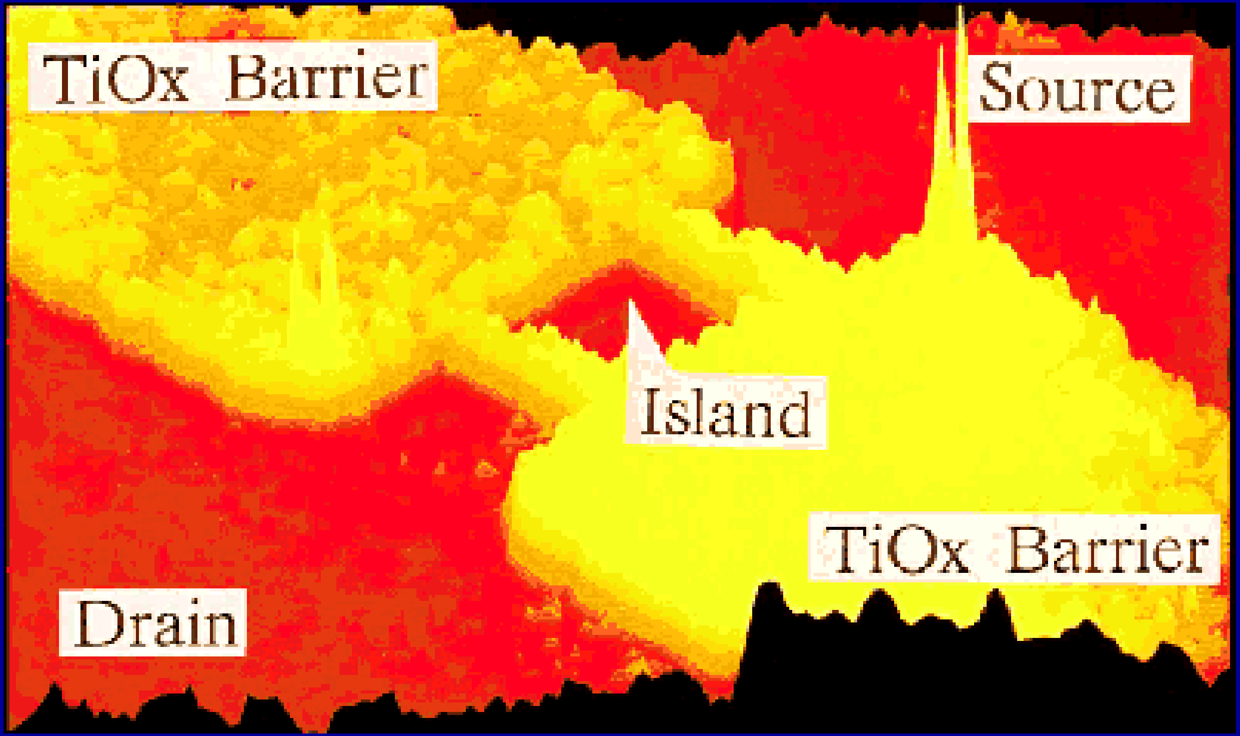
C. Leiber et. al. , Harvard U

Room temperature Single Electron Transistor (SET)

- •Single electron in "island" controls current flow from source to drain

- •Typical sizes of the TiOx lines are 15-25 nm widths and 30-50 nm lengths.

- •Typical island sizes are 30-50 nm by 35-50 nm



Courtesy, NEC, IEDM 2000, PP 481

Outline

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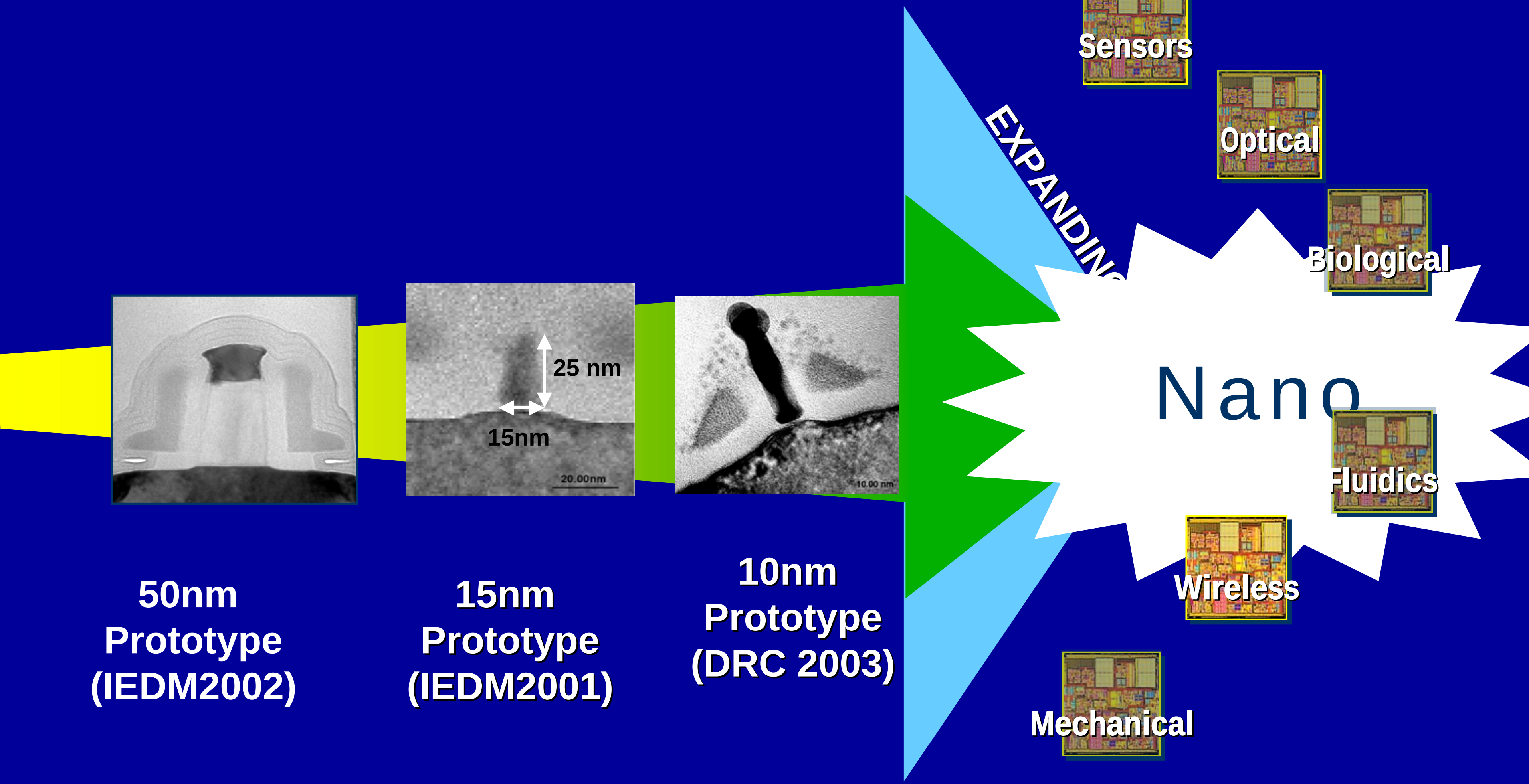
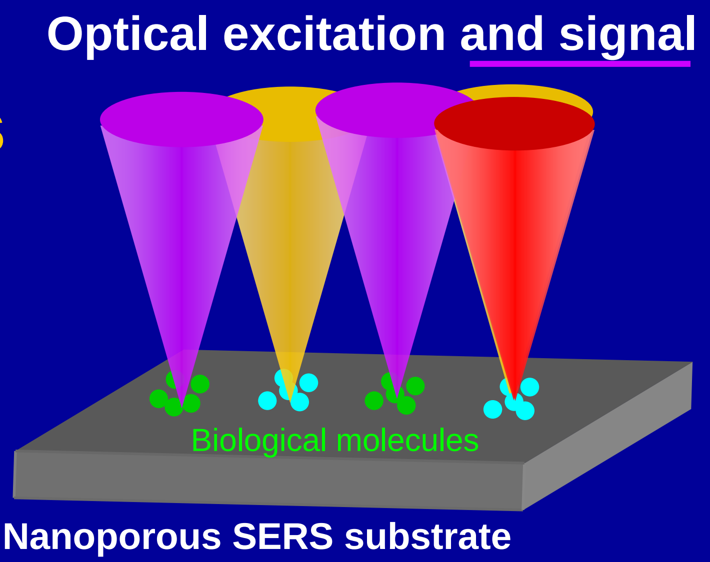
Expanding Moore's Law



 Silicon manufacturing infrastructure will enable innovation

Nano-Scale Biomolecular Analysis

Applications: Single molecule detection, protein detection, biological and chemical sensors



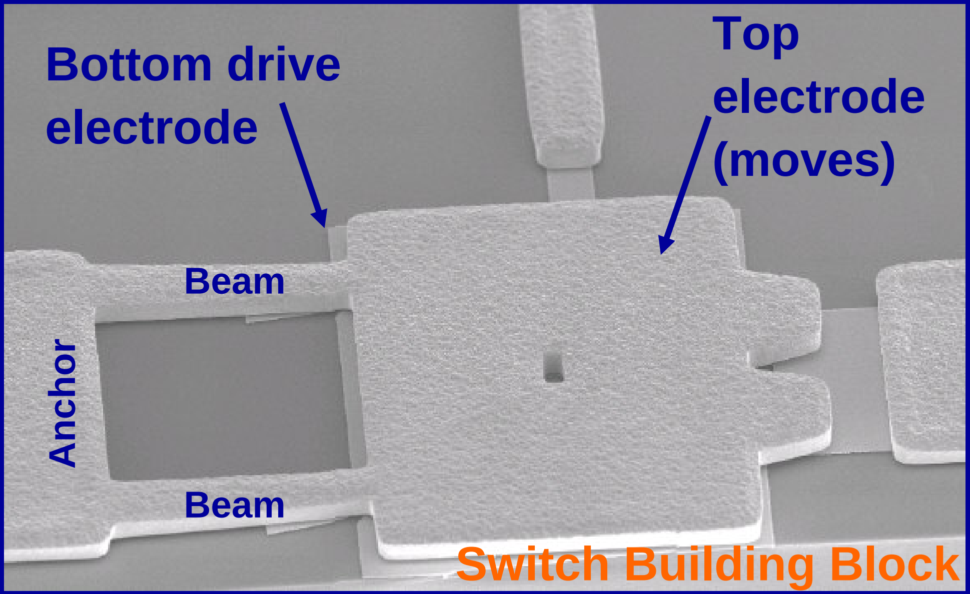
1. Transportation of Analytes

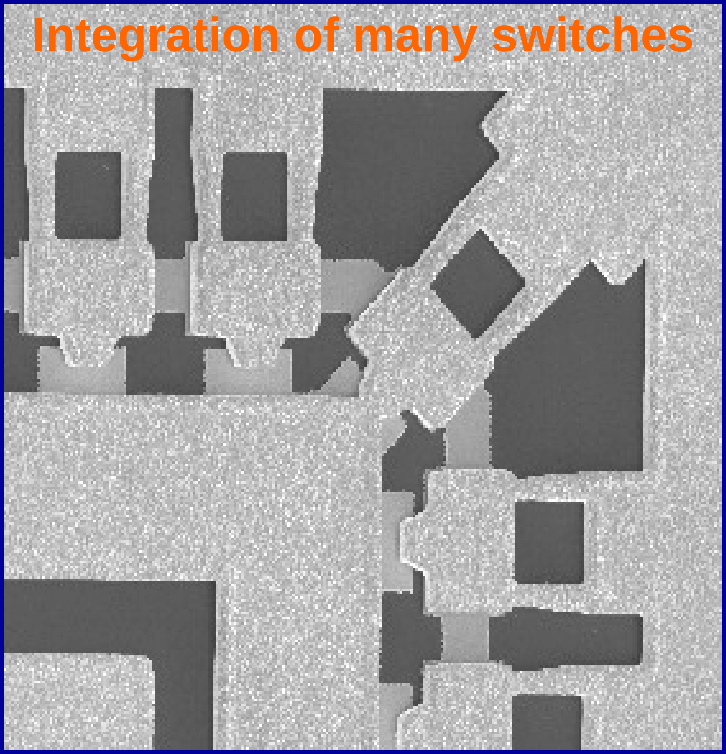
- 3D Hydrodynamic Focusing

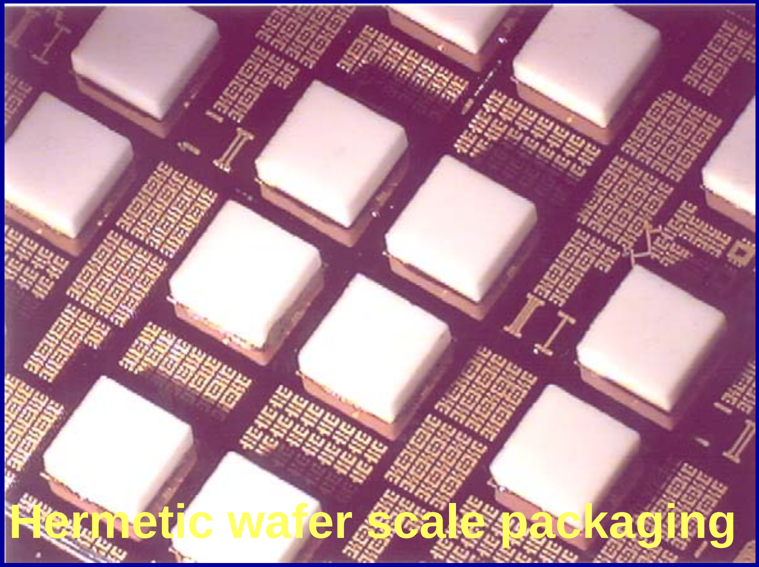
2. Detection of Analytes

- Nanoporous Substrates

MEMS for RF switching



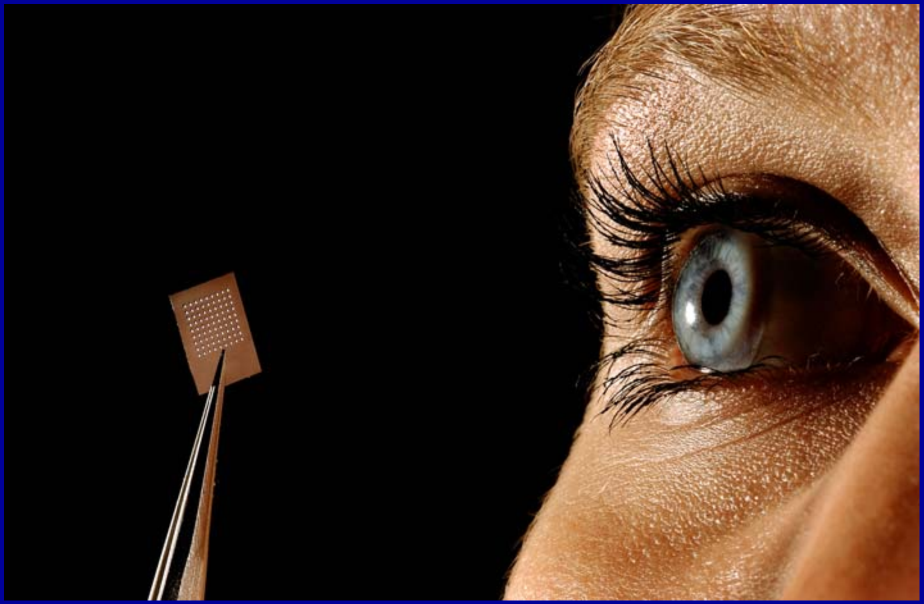


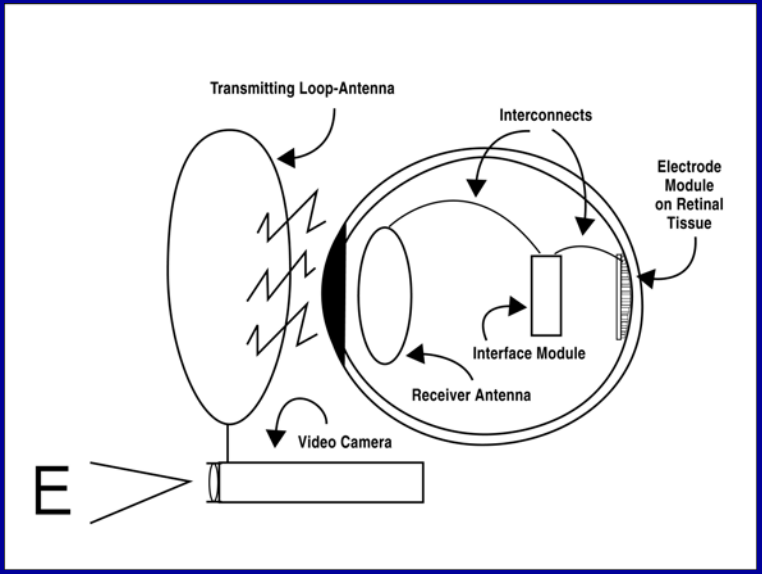


- Laterally lithography requirements are only n-5:
  - Mechanical devices are large10 µm -100 µm
- Vertically:
  - Layer thickness control requirement are extremely stringent: **"Nanometer sized gaps"**
  - Advanced materials with excellent mechanical and electrical properties are needed

Seeing the future

- Silicon based aid for total blindness
  - External camera, wireless link, MEMS based neural stimulation
  - Fully implantable





Courtesy, Sandia National Lab (www.sandia.gov)

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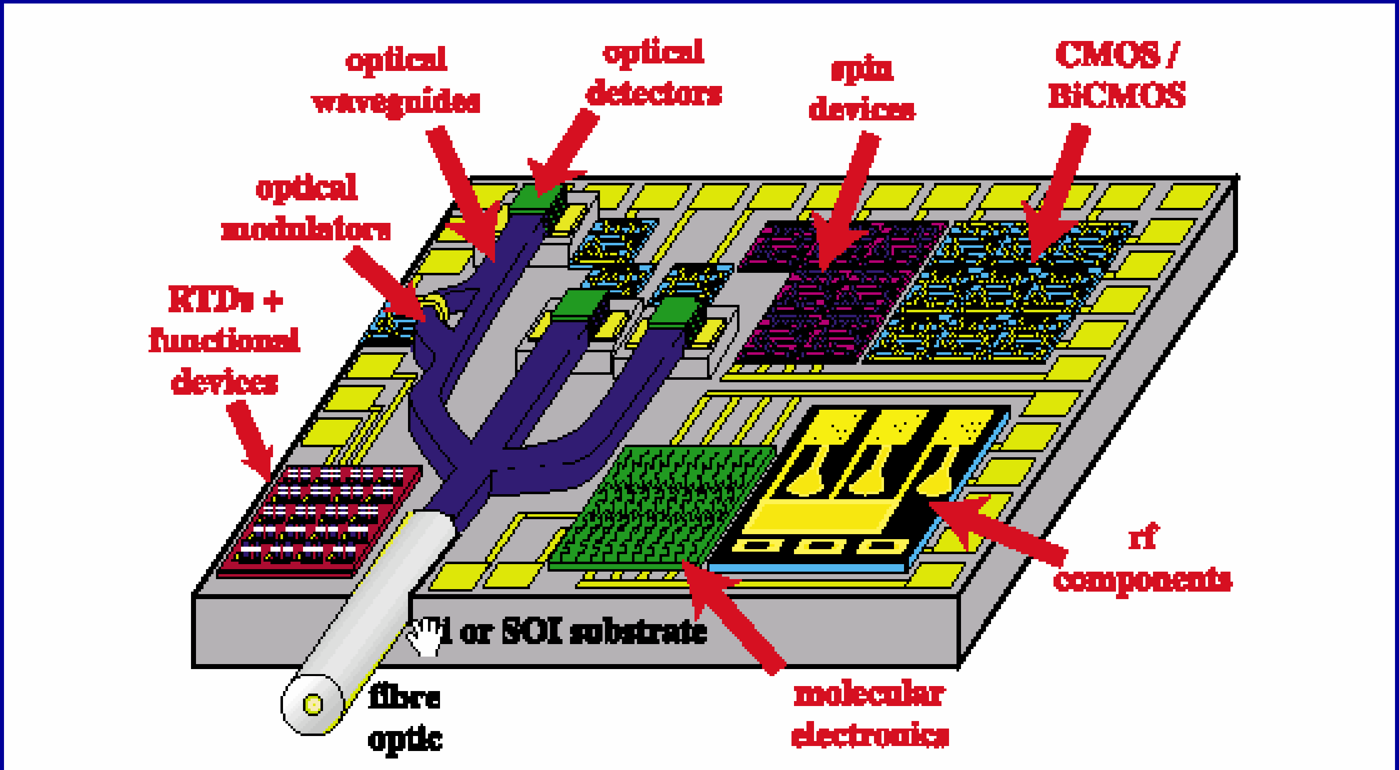
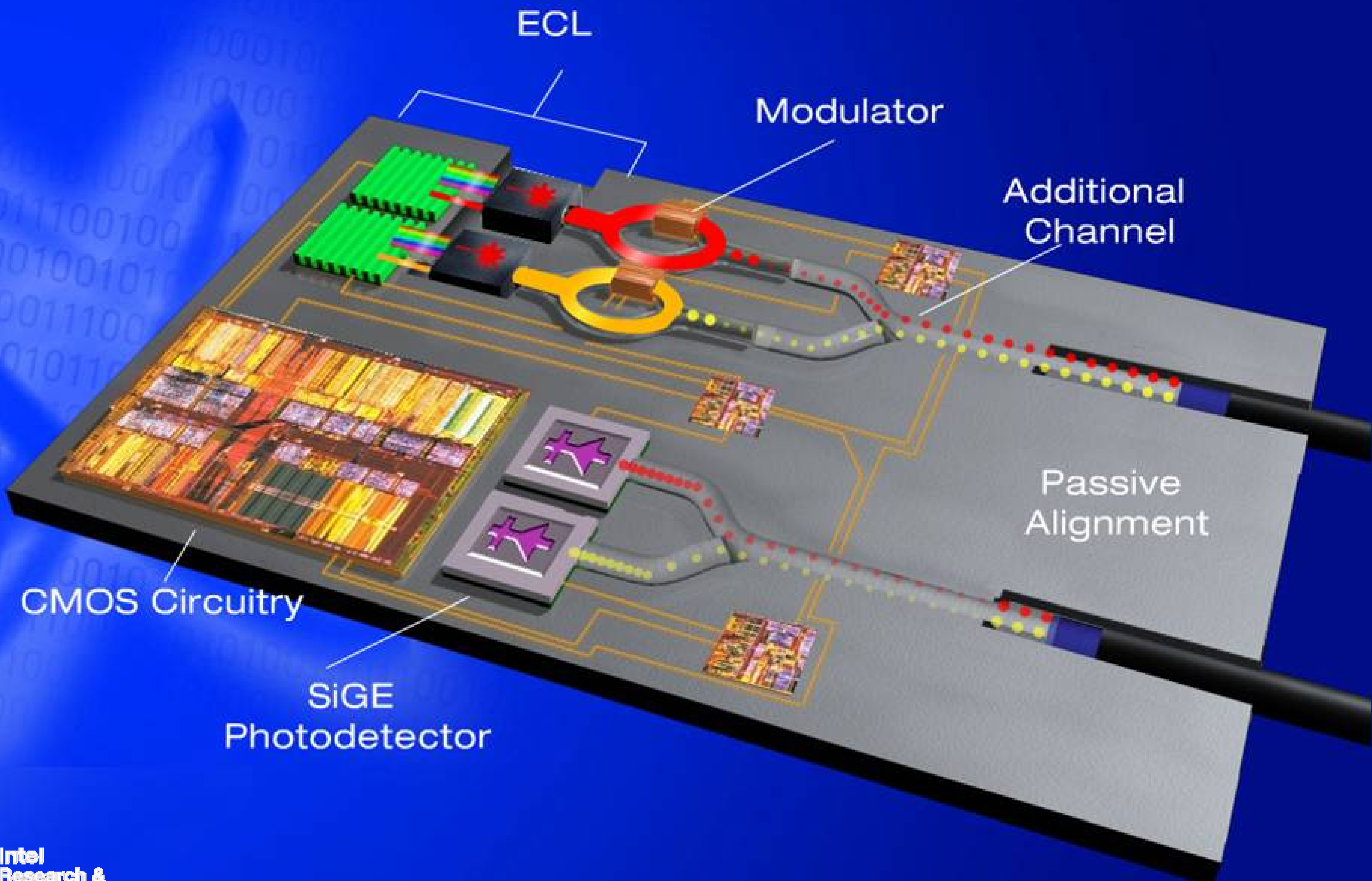
Heterogeneous integration of alternative technologies*



**European Technology Roadmap for Nanoelectronics*

Silicon integration platform

Silicon Photonics Vision



Intel
Research &
Development

Anthropomorphic Machines

Electrical complexity will be very high! The Sony robot depicted has over 40 IC's, tens of sensors, & novel actuation devices (muscles)

Innovation is in the integration of Conventional components

Sony SDR 4X Robot
Dr. Makimoto, IEDM 2002

Courtesy, Sony Corporation

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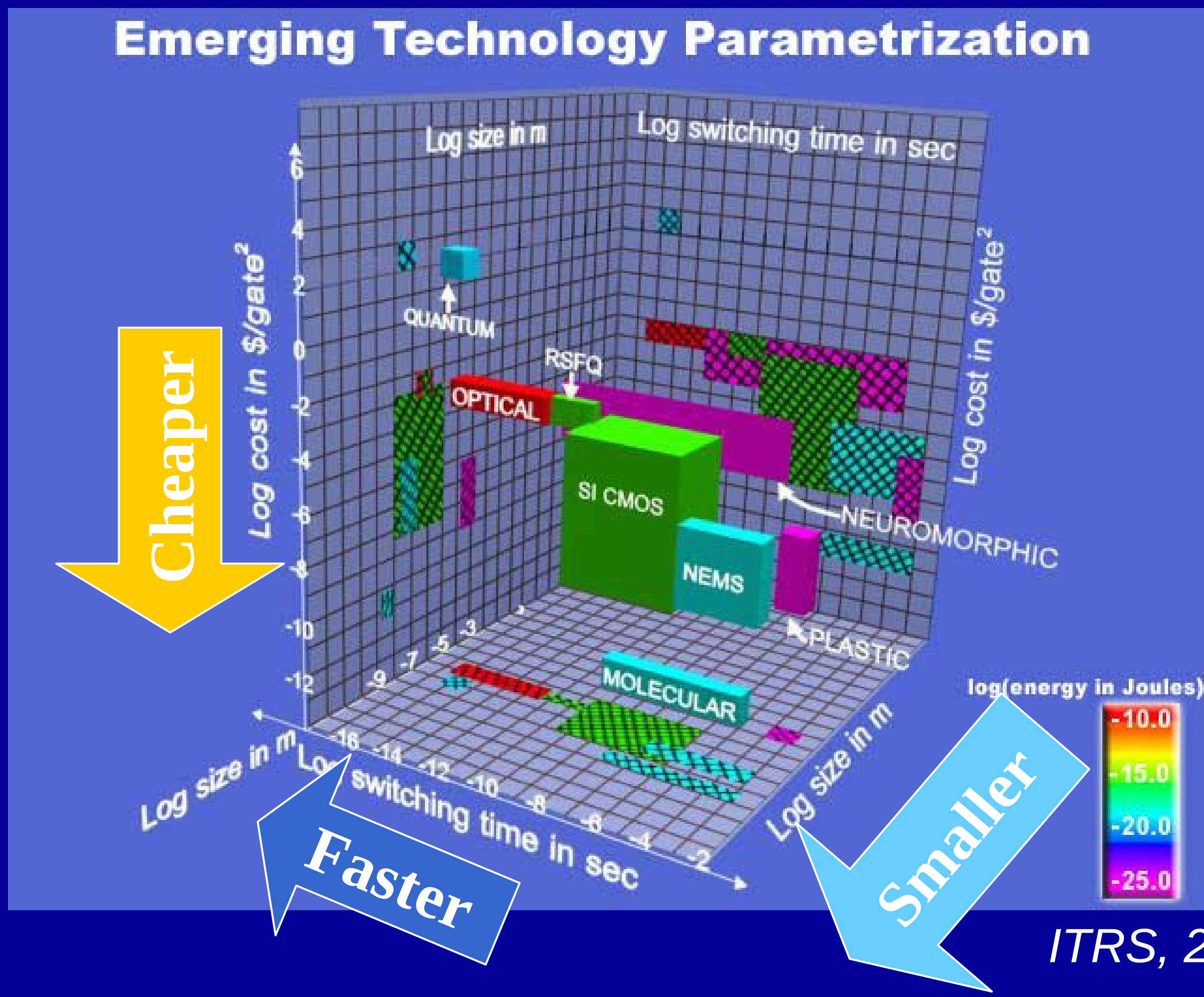
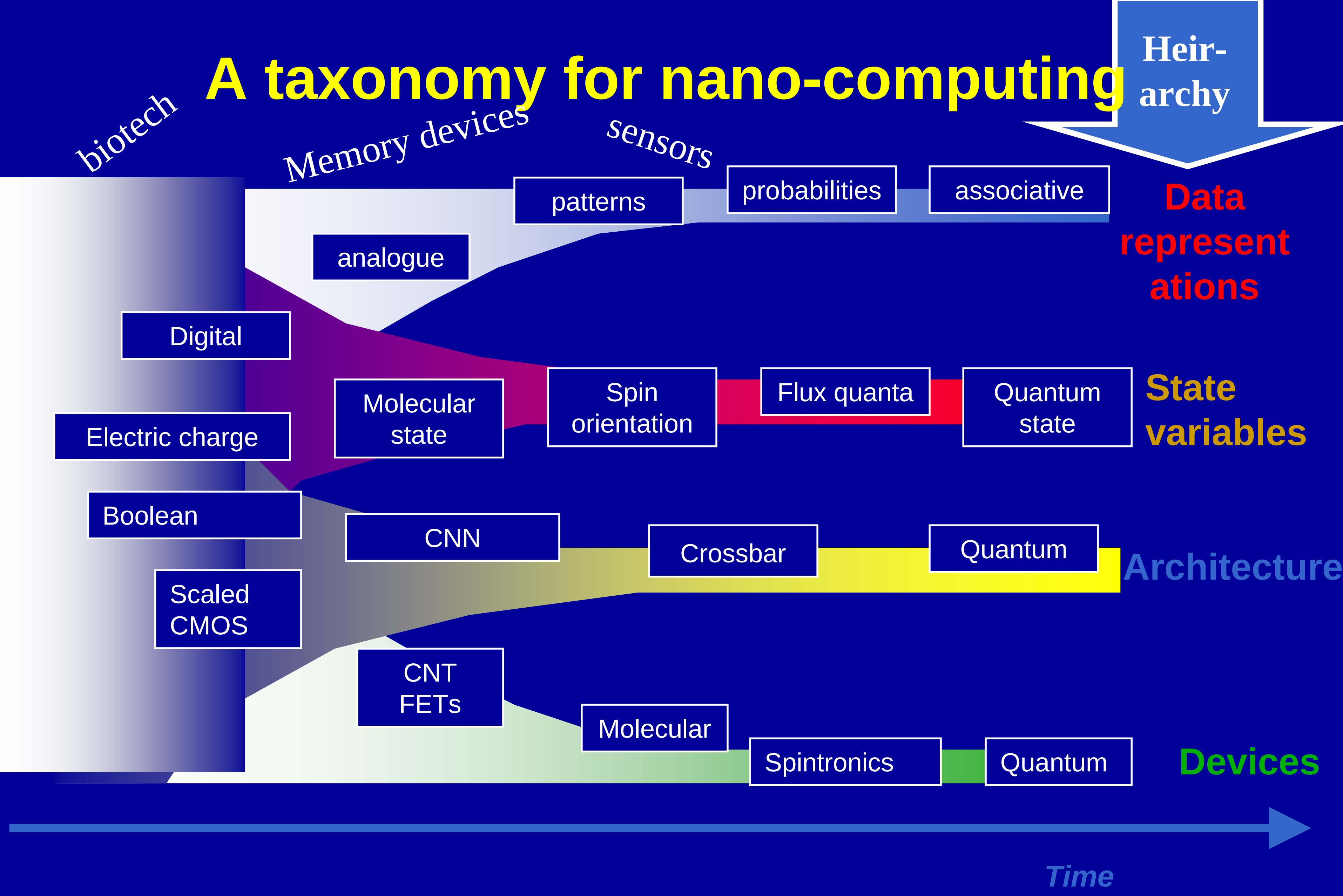
Radical technologies beyond CMOS



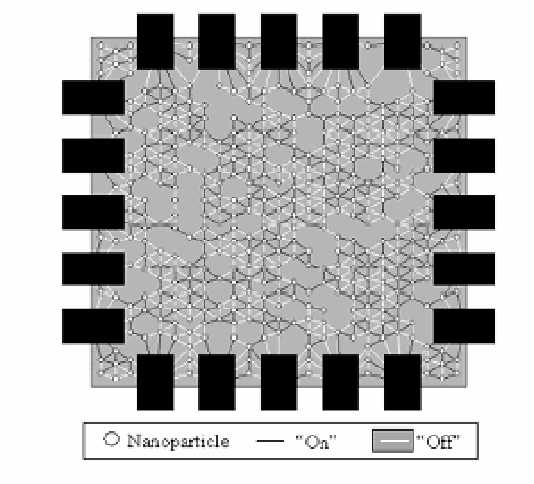
ITRS, 2001

Nothing beats scaled silicon but nanotechnology can complement

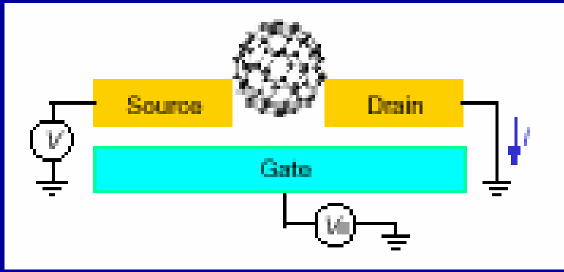
A taxonomy for nano-computing



Molecular logic



- 2D self assembled arrays*
  - Nanoparticles connected by programmable molecules
  - No gain, slowww
  - * J. M. Tour et. al Rice
- Back gated 3 terminal devices
  - Molecule acts as channel
  - No gain, very low current, slowww
  - McEuen et.al. Cornell



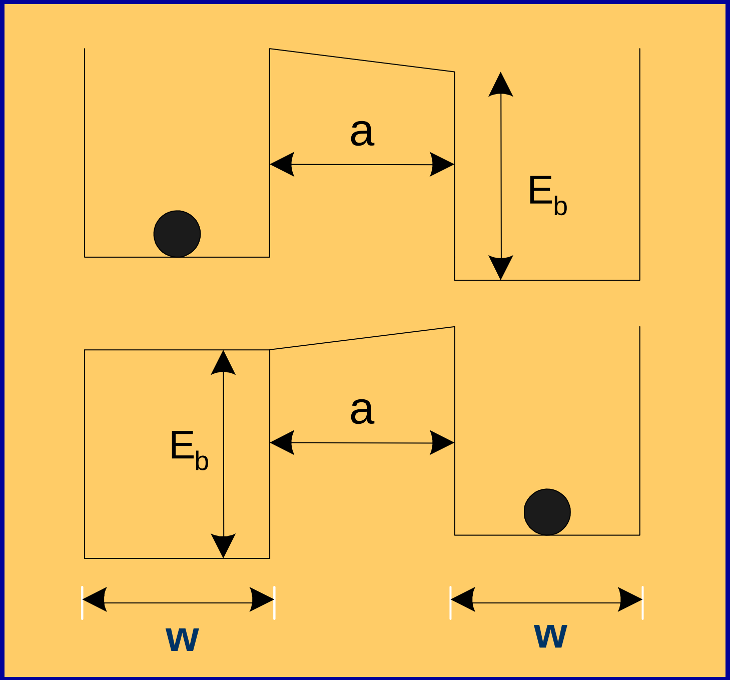
Very early stage research – contacts are critical

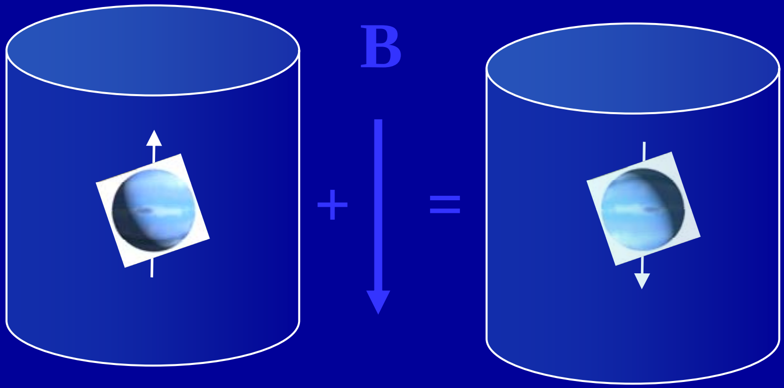
One possibility – a classical spin based switch

Charge

$\Delta E_b(e\text{-}) \sim 1.7X10^{-2}eV$ >> $\Delta E(spin) \sim 8.6X10^{-8}eV$

Spin

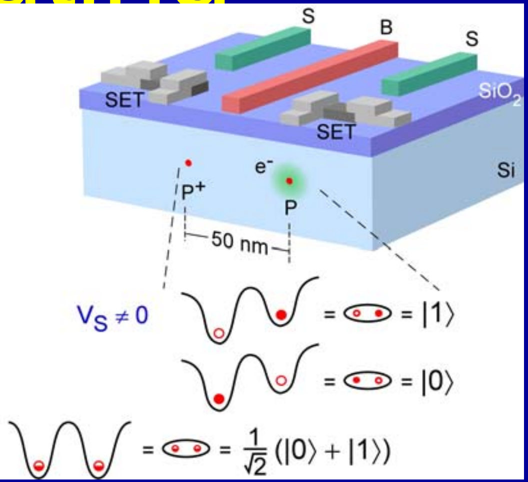




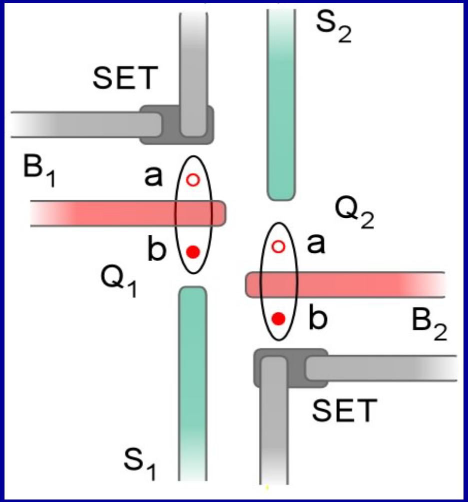
$\downarrow \Delta E \Rightarrow \downarrow$ **density?**
$\downarrow \Delta E \Rightarrow \downarrow$ **speed?**
$\downarrow \Delta E \Rightarrow \downarrow$ **heat ?**

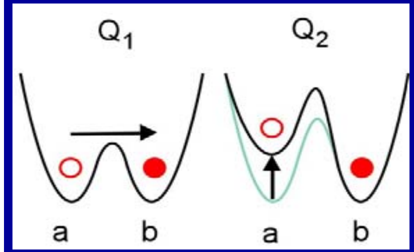
Issues are injection, extraction and coherence

Quantum computing



- Utilizes single phosphorous atoms implanted in silicon
- Gate electrodes control entanglement of the wavefunctions
- Qubit spacing of order 30 nm
- Quantum error correction difficult - 6 correction bits per single information bit
- Single logical qubit not yet demonstrated
- Large, well organized program in Australia





Most speculative of alternative logic

Innovation and research will be the catalyst

- Well coordinated, well funded international research and development program is needed
- Netherlands is well positioned to play critical role
  - Respected science
  - US/European gateway

Conclusions

- Nanotech innovation can help Extend Moore’s Law
- Silicon manufacturing infrastructure can help expanding Moore’s Law
- Silicon provides the ideal platform for heterogeneous Integration of nanotechnology
- Radical new nanotechnologies will emerge by 2020
- Worldwide research and innovation needed